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EFFECTIVENESS OF MOISTURE-EXCLUDING COATINGS ON WOOD¹

By GEORGE M. HUNT, *Principal Chemist, Forest Products Laboratory,² Branch of Research, Forest Service*

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INTRODUCTION

This circular brings together the results of various experiments made at the Forest Products Laboratory by different investigators on the moisture proofing of wood by coatings and impregnation treatments. The immediate objective of most of such treatments has been to reduce as much as possible the changes in moisture content of wood resulting from exposure to water, to the weather, or to changes in atmospheric humidity. The ultimate objective, however, has been to prevent the dimension changes that accompany changes in the moisture content of wood. In a few instances materials have been employed with the object of reducing the amount of shrinking and swelling with a given moisture change rather than trying to prevent changes in moisture content. Either method, if successful and practicable, will find a wide field of usefulness.

SUGAR TREATMENTS

It has been known for about 25 years that impregnating wood with sugar reduces its tendency to shrink and swell with changing moisture content. H. D. Tiemann, of the Forest Service, experimenting

¹ This circular embodies the results of moisture-excluding investigations by the Forest Service that have extended over more than 15 years. It has been the author's privilege to draw without restraint upon the accumulation of information that has resulted from studies on moisture proofing by various members of the Forest Products Laboratory staff. The author particularly wishes to make acknowledgment to M. E. Dunlap, who contributed the major part of the data in this report and mainly under whose supervision the work has progressed to its present status. In addition acknowledgment is made to H. D. Tiemann and the late N. de W. Betts, of the Forest Products Laboratory, who conducted the early experiments on moisture-retarding coatings that are reported here. Further acknowledgment is made to the Bureau of Aeronautics, Navy Department, the Army Air Service, and the National Lumber Manufacturers' Association for substantial financial cooperation in carrying on these investigations.

² Maintained by the U. S. Department of Agriculture at Madison, Wis., in cooperation with the University of Wisconsin.

at Yale University before the establishment of the Forest Products Laboratory at Madison, Wis., found that the shrinkage of wood could be reduced 50 per cent or more by means of sugar treatment. His experiments, however, were not continued long enough to determine the minimum amount of sugar required per cubic foot in order to be effective nor long enough to work out the practical limitations of sugar treatment. The use of sugar for treating wood was covered at that time by the Powell process patent,³ and various patents covering the use of sugar have been issued since. Powell had in mind the prevention of decay, however, rather than the reduction of shrinkage.

In 1915, H. Bradley, at the Forest Products Laboratory, treated six longleaf pine paving blocks with sugar solution, securing an average absorption of about 2.1 pounds of sugar per cubic foot. He also treated six blocks with coal tar creosote, securing an average absorption of about 15.1 pounds per cubic foot. The creosote treatment materially retarded moisture changes and the accompanying dimension changes. Bradley, however, was unable to find that the sugar treatment had affected the tendency of the wood to shrink and swell. He was interested in the swelling of paving blocks in city streets and was concerned with major effects only. His sugar absorptions were probably too low to have a marked effect on shrinking and swelling.

In 1928, H. D. Tiemann, at the Forest Products Laboratory, made a minor experiment with small blocks of sap maple and birch. He injected different amounts of sugar and molasses into the blocks and measured their shrinkage after kiln drying. The results are summarized in Table 1. It may be noted that all of the sugar and molasses treatments greatly reduced the shrinkage and that the greatest reductions were obtained in the blocks treated with full-strength molasses and the strong sugar solution. The amount of sugar absorbed was high.

TABLE 1.—Results of minor tests on sugar-treated blocks

Kind and size of blocks	Treating material	Dry sugar absorbed		Shrinkage of blocks from wet to air-dry condition, based on green width	Reduction in shrinkage caused by sugar treatment ^a
		Weight	Based on air-dry weight of wood		
		Grams	Per cent	Per cent	Per cent
Sap maple blocks, 1 by 4¼ by 2½ inches.	(Water (control).....)			6.19	
	30 per cent sugar solution.....	43.7	40.7	1.09	82.4
	17 per cent sugar solution.....	31.0	28.9	2.38	61.6
	9 per cent sugar solution.....	29.7	27.3	3.09	50.0
	Molasses, full strength.....	55.0	51.2	.95	84.7
	Molasses, half strength.....	42.2	39.4	2.14	65.4
Sap birch blocks, ¾ by 6½ by 2½ inches.	(Water (control).....)			5.56	
	30 per cent sugar solution.....	21.4	36.3	1.54	72.3
	17 per cent sugar solution.....	15.6	26.5	2.32	58.3
	9 per cent sugar solution.....	7.9	13.4	3.71	33.3
	Molasses, full strength.....	37.0	62.8	1.23	77.9
	Molasses, half strength.....	28.7	48.7	1.54	72.3

^a Percentage based on the shrinkage of the water-treated blocks.

³ POWELL, WILLIAM. VULCANIZED WOOD AND PROCESS OF VULCANIZING SAME. (U. S. Patent No. 755,240.) U. S. Patent Office, Off. Gaz. 109: 917. 1904.

The various experiments with sugar treatment indicate that sugar has an effect on the shrinkage, swelling, and other properties of wood sufficiently marked to warrant thorough study. Whether practical use can be made of this effect and what the practical limitations are can be determined only after careful investigation.

PRE-WAR EXPERIMENTS WITH COATINGS

The first experiment at the Forest Products Laboratory on the effectiveness of coatings in retarding moisture and dimension changes was started in 1914. Specimens of basswood and western larch, about 1 by 8 by 15 inches in size, were used and coatings of the following materials applied: House paint, shellac, varnish, bakelite varnish, paraffin, and linseed oil. Impregnation treatments with coal tar creosote, glutrin, and sugar were included, as well as a high-temperature treatment of the wood. The specimens were oven dried before treatment. After treatment they were hung out of doors under a shed, and weights and measurements were taken for about a year, after which they were again brought indoors and allowed to dry and shrink under the dry, warm conditions prevailing indoors in the winter.

The results were not entirely conclusive, but they showed that the sugar, creosote, and high-temperature treatments slowed up dimension changes materially, that a linseed-oil coating had little effect, and that the paraffin coating gave the best results of the various coatings tried in this experiment.

WAR-TIME EXPERIMENTS

During the World War much trouble was encountered with airplane propellers getting out of balance and shape as a result of moisture changes. The Forest Products Laboratory was requested by the War Department to study the effectiveness of the propeller finishing methods then in use and, if possible, to devise better methods. Under the war-time pressure for results, a method of test was adopted and a large number of coatings tried in an effort to find quickly something that would be effective and practical. As a result, the aluminum-leaf process was developed and put into use. Nothing more effective has been found to this day, but aluminum paints and varnishes are now commonly recommended by the Forest Products Laboratory instead of the aluminum leaf because they are nearly as effective, and are much more convenient to apply.

The experiments were made on birch panels, five-eighths by 4 by 8 inches in size, with the edges and corners rounded and sanded. The panels were coated on all surfaces. Since constant-humidity rooms, maintained at low humidity, were not available at that time the panels were merely kept in the workroom before and during the finishing or treating period. After the finish or treatment had thoroughly dried, the panels were weighed and placed in a room kept at a temperature of 75° to 80° F. and a relative humidity of 95 per cent or more. Weights were taken after 3 days and again after 1 week and 2 weeks additional exposure. The comparative increase in weight through the different finishes was taken as an indication of their ability to prevent moisture changes. The test was not highly accu-

rate, but it afforded a ready means of distinguishing between highly effective, moderately effective, and ineffective treatments or coatings.

Tests made later showed that the species of wood and the size and shape of the specimens had practically no influence upon the results of the test. The principal factor affecting the results was the permeability of the coating. It was also shown that the humidity test was the logical test to use except in testing coatings or treatments intended primarily to protect against liquid water.

During and immediately after the World War, the humidity test was applied to a large number of commercial spar varnishes, rubbing varnishes, cellulose varnishes, enamels, rubber coatings, metal coatings, and miscellaneous coatings and treatments. Comparisons were made of dipped and brushed coatings, of air-dried and oven-dried coatings, and of the relative effectiveness of different numbers of varnish coatings.

The humidity test gave no indication as to the length of time the effectiveness of the coating would be maintained. A few supplemental tests were therefore made to learn something about how the coatings behaved on soaking in water or exposure to the weather. These tests gave indicative results only, which could not be compared numerically.

The water test was made, in most cases, by applying varnishes to glass and, after thorough drying, immersing the coated glass for 10 days in water at room temperature and noting the extent to which the coating softened or discolored. Two water-submersion tests were made, however, upon electroplated-copper and vulcanized-rubber coatings over wood panels in which weights were taken to determine the moisture-excluding effectiveness.

The weather-exposure test was made on panels very similar to the panels used in the humidity tests. The backs of the panels were coated with black paint, and the faces were finished by applying one coat of filler and one coat of the finish to be tested. After drying, the panels were hung on a rack at an angle of 60° with the horizontal. The rack was then placed upon a flat roof in such a manner that the panels faced south. The upper part of the face of each panel was protected from the weather so that its condition could be compared later with the condition of the exposed part.

RESULTS OF EXPOSURE TESTS

It was found that the oil varnishes stood up during three or four months of winter weather without crazing or checking while the cellulose lacquers failed by cracking and surface wear in less than two months. No doubt all of the finishes would have remained in good condition longer if three or more coats had been applied instead of one. This test did not give any important results.

RESULTS OF WATER TESTS

The varnish films on glass plates all became soft after soaking for 10 days in water at room temperature. Some of them turned white, and others did not, but all of them obviously were very much affected by the water. The effects of the soaking on the color of the varnishes tested are given on page 7.

A hard-rubber-coated specimen was furnished by a manufacturer without details as to its preparation. The rubber appeared to have been vulcanized directly on the wood. This specimen was soaked in water at room temperature and weighed at intervals to determine the amount of water absorbed. A water-soaking test was also made on a specimen electroplated with copper by another manufacturer. These coatings appeared to be impervious. Both coatings, however, were rather thick and heavy, and did not appear to be suitable for general purposes. The absorptions shown in Table 2, except at the defect noted in the copper coating, are probably due to variations in moisture on the surface of the coating which could not be removed readily with a cloth, or due to experimental inaccuracies.

TABLE 2.—*Results of water submersion tests on hard-rubber and electroplated-copper coatings*

[One specimen each]

Coating	Absorption in 0.0001 pound after soaking for—											
	1 day	2 days	3 days	5 days	6 days	7 days	8 days	12 days	13 days	14 days	15 days	17 days
Hard rubber.....	-----	7	1	-----	9	6	2	-----	8	-----	-----	6
Electroplated copper.....	10	7	7	5	-----	-----	-----	15	11	10	25	-----

¹ A small defect in the coating admitted water at this time and the coating cracked.

RESULTS OF WAR-TIME HUMIDITY TESTS

METAL COATINGS

Table 3 gives the results obtained in the humidity test with metal-leaf coatings and an electroplated-metal coating. For the sake of comparison, the table includes the results obtained from untreated panels, from the best varnish tested up to that time, and from the standard linseed oil and wax finish then being used on aircraft propellers. The electroplated panel was plated with copper and sent to the laboratory by a manufacturer. The details of the method of application were not disclosed.

TABLE 3.—*Results of humidity tests of metal coatings*

[War-time experiments]

Treatment	Number of specimens averaged	Average absorption in 0.0001 pound for—				
		3 days	10 days	17 days	24 days	31 days
Silex filler, gold size, aluminum leaf and 3 coats of black lacquer.....	2	¹ -2.5	1	2	² -0.5	5.5
Silex filler, 1 coat of rubbing varnish, gold size, imitation gold leaf, 1 coat spar varnish.....	3	2.6	5.3	9.6	-----	-----
Silex filler, 1 coat of rubbing varnish, gold size, aluminum leaf, 1 coat spar varnish.....	1	0	3	5	-----	-----
Silex filler, 3 brush coats waterproof varnish No. 2.....	10	15	54	87	-----	-----
Electroplated-copper coating.....	1	0	2	5	11	-----
Five applications of hot linseed oil and two coats of wax.....	2	167	437	569	-----	-----
No treatment.....	10	245	507	619	-----	-----

¹ This negative value may have resulted from loss in weight of the coating.

² This negative value may have resulted from an error in weighing.

Table 3 shows that the metal coatings were nearly waterproof. Their superiority over the varnish and the linseed-oil coatings is outstanding. The aluminum-leaf coating was chosen as best, all things considered. The electroplated coating was heavy, did not

adhere satisfactorily to the wood, and would be more expensive and inconvenient to apply than the leaf coatings. It would also be difficult to repair if damaged. The aluminum leaf was preferred to the imitation gold leaf because it appeared to be tougher and therefore less subject to damage in use or in application. The metal-leaf coatings in these experiments were dried by heating the specimens in an oven at 115° F. and 45 per cent relative humidity, but it was found later that the use of heat in drying was unnecessary.

The results show that wood properly finished with an aluminum-leaf coating will change moisture content at an extremely slow rate. Under fluctuating conditions, which would favor loss of moisture part

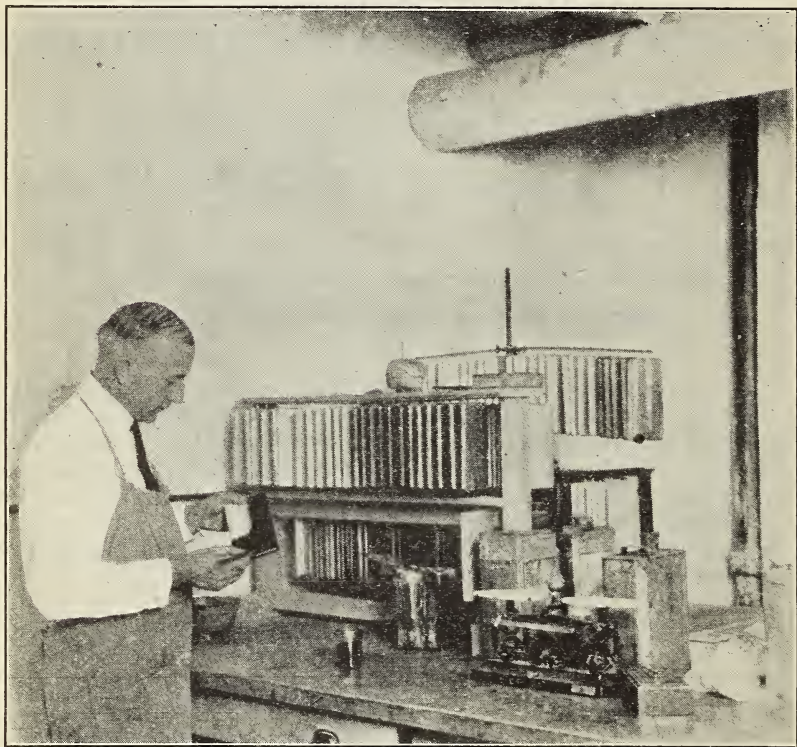


FIGURE 1.—Brushing coatings on test panels

of the time and gain of moisture part of the time, the moisture content of the wood will remain nearly constant as long as the aluminum-leaf coating remains in good condition.

VARNISHES, BRUSHED AND AIR-DRIED

Thirty-nine varnishes recommended for outdoor use were secured from 23 varnish manufacturers. They were nearly all spar varnishes, which, in comparison with the harder varnishes used in furniture finishing and the like, have a relatively high percentage of oil and a low percentage of gum. High percentages of gums make coatings more brittle than the spar varnishes and therefore less suitable for outdoor use.

The test panels were first given a coat of silex filler, which was allowed to dry for 12 hours. Then three coats of the varnish were applied by brush to the panels (fig. 1), three days being allowed between coats for drying. The final coat was allowed to dry for eight days before the humidity test was started. All except the last coat were sanded lightly to remove imperfections, but not heavily enough to disturb the main body of the coating. The finishing was all done in an ordinary room without humidity control.

The results of the humidity and water tests on the 39 varnishes are given in Table 4. Considerable variation was found in the amount of moisture absorbed through the different coatings during the 17 days' exposure to a high relative humidity. This may have been due in part to imperfections in the methods of application and test. The varnishes were not thinned for application, but were applied just as received from the manufacturers. The viscosities varied somewhat, and therefore the spreading qualities of the varnishes were not all the same which fact may have caused differences in the amounts of varnish spread on the different panels. The differences in results, however, are believed to be due mostly to inherent differences in the ability of the varnishes to retard the passage of moisture.

TABLE 4.—*Results of humidity and water tests of varnish coatings applied to wood specimens with brush and then air dried*¹

Name or kind of varnish	Number of specimens	Humidity test			Water test
		Average absorption in 0.0001 pound in—			
		3 days	10 days	17 days	
Air-drying varnish (black asphaltum)	2	16.5	56.5	86.0	Color very slightly affected.
Waterproof varnish No. 2.....	10	16.8	54.4	87.0	Greatly discolored.
Waterproof rubbing varnish V800.....	2	24.5	56.0	89.0	Color very slightly affected.
Waterproof varnish No. 1.....	16	22.2	67.1	104.0	Greatly discolored.
Black asphaltum.....	2	22.0	79.0	127.0	Color very slightly affected.
Exterior spar varnish.....	2	28.0	93.0	142.0	Greatly discolored.
Waterproof finishing varnish No. V801.....	2	32.0	85.5	143.0	Color very slightly affected.
Kauri varnish.....	2	33.0	97.5	150.0	Greatly discolored.
Spar varnish MS.....	4	31.2	99.0	152.5	Color very slightly affected.
Signal Corps spar varnish.....	4	37.5	116.8	173.2	Do.
Spar varnish S.....	2	38.0	118.0	179.0	Greatly discolored.
Marine spar varnish.....	4	44.0	123.5	181.5	Color very slightly affected.
Varnish No. 1551.....	2	40.5	125.0	186.0	Do.
Spar varnish A.....	2	55.0	138.0	192.0	Greatly discolored.
Spar varnish V (coated by manufacturer)	1	44.0	123.0	194.0	Color very slightly affected.
Water-resisting varnish.....	2	48.5	128.0	195.0	Do.
Water and ammonia proof varnish.....	2	47.5	121.5	197.0	Do.
Interior varnish.....	2	98.0	152.0	200.0	Greatly discolored.
Waterproof varnish K.....	2	48.0	139.5	206.5	Do.
Varnish M.....	2	45.5	137.0	209.0	Color very slightly affected.
Airplane varnish.....	2	53.0	151.0	209.0	Do.
Baking varnish.....	2	45.0	142.0	212.0	Greatly discolored.
Airplane spar varnish.....	2	43.5	130.5	212.5	Color very slightly affected.
Varnish P.....	2	48.0	146.5	219.0	Do.
Naval varnish.....	2	51.0	154.0	219.0	Do.
Special spar varnish.....	2	57.0	151.0	222.0	Greatly discolored.
Waterproof varnish No. 84.....	2	52.0	155.0	222.0	Color very slightly affected.
Spar varnish B.....	2	48.0	151.0	225.0	Do.
Air-drying varnish.....	2	59.0	150.0	225.0	Greatly discolored.
Spar varnish V.....	2	53.5	159.0	226.0	Color very slightly affected.
Floor varnish.....	2	63.0	159.0	227.0	Greatly discolored.
Marine spar varnish No. 1017.....	2	54.5	155.0	229.0	Color very slightly affected.
Spar varnish F.....	2	60.0	161.0	230.0	Do.
Body-finishing varnish.....	2	56.5	137.0	235.0	Greatly discolored.
All-purpose varnish.....	2	64.5	182.0	256.0	Color very slightly affected.
Waterproof varnish C.....	2	75.0	201.5	276.0	Do.
Insulating varnish (air-drying).....	2	68.0	206.0	281.0	Greatly discolored.
Special baking varnish.....	2	73.0	210.0	295.0	Color very slightly affected.
Varnish No. 706.....	2	72.0	198.0	295.0	Greatly discolored.

¹ The wood used was yellow birch with average dimensions of 0.6 by 4 by 8 inches; average surface area of 0.54 square foot; average weight of 0.49 pound when air dry; and average volume of 0.011 cubic foot.

Three varnished samples after 17 days' exposure showed absorptions between 0.0086 and 0.0090 pound, or about 14 per cent of the absorption by untreated specimens. Fourteen showed absorptions between 0.01 and 0.02 pound (16 to 32 per cent), and the remainder between 0.02 and 0.03 (32 to 48 per cent of the absorption by untreated specimens). Untreated specimens absorbed 0.0619 pound, or a little more than twice the amount absorbed by the least effective of the varnishes.

These results show that varnishes of the type tested should not be depended upon for a high degree of moisture proofing, but, at least when they are fresh, they will retard moisture changes very greatly in wood exposed to fluctuating atmospheric humidity. Wood once dried to a suitable moisture content and then properly varnished on all sides will remain much closer to that moisture content under fluctuating conditions than similar wood unvarnished.

COMPARISON OF AIR-DRIED AND OVEN-DRIED VARNISH COATINGS

Experiments were made to learn whether forced drying of the varnish coatings in an oven would affect their moisture-resisting properties. Nineteen varnishes were applied to panels exactly as in the brushing and air-drying experiments reported in Table 4, except that each coat was dried in an oven for 6 hours at 115° F. and 45 per cent relative humidity and then air dried for 18 hours. It was found that a higher temperature than 115° F. was not suitable because it blistered the varnish.

The oven-dried coatings appeared to be more effective on some panels and on others less effective than the air-dried coatings. Some panels showed no appreciable difference between the air-dried and oven-dried coatings. The comparative results from several of these panels are given in Table 5, columns 3 and 5. The results indicated no important or general advantage or disadvantage in moisture-retarding effectiveness as the result of oven drying. The differences found may have been due to imperfections in the methods of application and test or to inherent differences in the effect of the oven drying on the different varnishes.

TABLE 5.—*Comparison of dipped and brushed and air-dried and oven-dried varnish coatings in humidity tests*

[Each result is the average from two specimens except as otherwise noted]

Name of varnish	Average absorption in 0.0001 pound in 17 days			
	Air-dried		Oven dried	
	Dipped	Brushed	Dipped	Brushed
Waterproof varnish No. 2.....	55	¹ 87	56	² 83
Waterproof varnish No. 1.....	70	³ 104	67	² 104
Waterproof rubbing varnish No. V800.....	79	89	87	100
Kauri varnish.....	113	150	124	143
Waterproof finishing varnish No. V801.....	127	143	141	186
Spar varnish F.....	⁴ 170	226	152	-----
Airplane spar varnish.....	172	213	169	212

¹ Average from 10 specimens.

² Average from 6 specimens.

³ Average from 16 specimens.

⁴ Average from 4 specimens.

A similar comparison was made between air-dried and oven-dried coatings applied by dipping. (The dipping method is described in the next paragraph.) The results (columns 2 and 4, Table 5) were parallel to those from the brushing experiments in that they showed no consistent advantage or disadvantage for either method of drying.

COMPARISON OF BRUSHED AND DIPPED VARNISH COATINGS

An experiment was made to determine whether applying varnish by dipping would give a better and more effective coating than by brushing. Seven of the varnishes shown in Table 4 were applied by dipping, using a filler and three coats of varnish and drying exactly as in the case of the air-dried brushed coats. The dipping was done by means of a motor and pulley arrangement which withdrew the specimen from a can of the varnish at a uniform rate. A speed of withdrawal of 1 to 2 inches per minute was found best. A very smooth finish was obtained, which required no sanding.

The results of the comparison of the air-dried dipped and brushed varnish coatings are shown in columns 2 and 3 of Table 5. The dipped coatings in every case showed materially greater effectiveness than the brushed coatings. This was probably due to the combined effect of the greater amount of varnish applied by dipping, lack of injury to the coating by sanding, and fewer imperfections in the coating. Whether the superiority of the dipped coatings would continue during long exposure or use was not determined, but presumably it would.

A parallel experiment was made in which the coatings, instead of being air-dried, were dried in an oven at 115° F. and 45 per cent relative humidity for six hours, as previously described. The results, which are shown in columns 4 and 5 of Table 5, parallel the results of the air-drying tests in that the dipped coatings always showed some superiority over the brushed coatings of the same varnish.

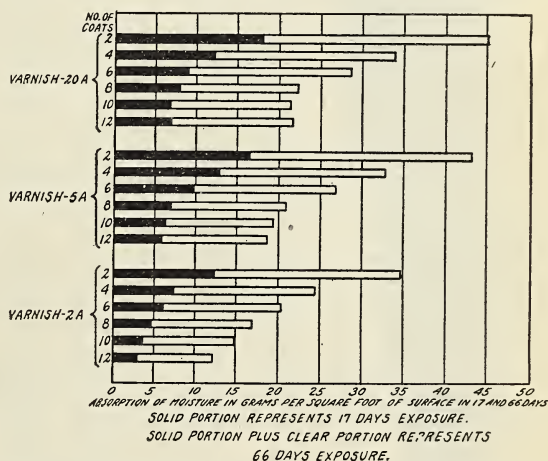


FIGURE 2.—Relative effectiveness of 2 to 12 coats of varnish in preventing the absorption of moisture by wood when exposed to a relative humidity of 95 to 100 per cent. Tests made with yellow birch panels plus filler plus the number of coats of spar varnish indicated

EFFECT OF THE NUMBER OF COATS OF VARNISH

In order to determine the effect on moisture absorption of increasing the number of coats of varnish, three series of panels were prepared in which 2, 4, 6, 8, 10, and 12 coats were applied in each series to yellow birch panels. The panels were prepared in duplicate and a different spar varnish used in each series. A silux filler was first applied, and then the coatings were applied with a brush. An average of four days was allowed for drying between coats and six days after the final coat. No attempt was made to get a fine smooth finish by sanding or rubbing. The six panels to receive 12 coats were started first, then when they were ready for the third coat, the 10-coat panels were started, and so on with the 8, 6, 4, and 2 coat

panels. In this way all the panels received their final coat on the same day and had the same amount of drying before the start of the test. They were then exposed to the humidity test and weighed at intervals up to 66 days. The results for the 17-day and the 66-day exposures are shown in Figure 2.

There was a general increase in moisture-excluding effectiveness as the number of coats increased. Varnish 2-A showed a consistent

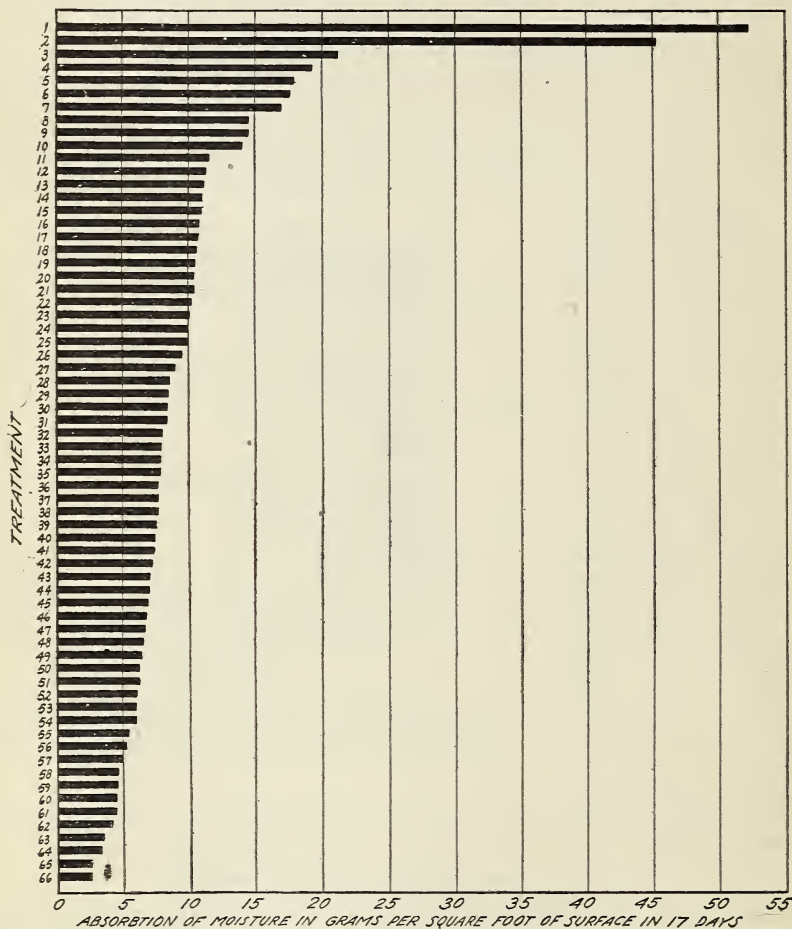


FIGURE 3.—The relative effectiveness of different enamels in preventing the absorption of moisture by wood when exposed for 17 days to a relative humidity of 95 to 100 per cent

(For key to treatment see page 11)

increase up to 12 coats, and additional coats might have added to the effectiveness. Varnish 20-A appeared to have closely approached its limit at eight coats, and varnish 5-A showed only slight gain after eight coats.

The use of so many coats for moisture-excluding purposes would probably be less practical in most cases, than the use of fewer coats of a varnish containing aluminum powder.

EFFECTIVENESS OF ENAMELS

A number of experiments were made to compare the effectiveness of clear spar varnishes and enamels made by adding pigments to the varnishes. Most of the enamels used were made in the laboratory, but a few commercial enamels were included. The pigments in the laboratory mixtures were ground into the varnish with a mortar and pestle. The combinations of materials and methods of drying employed are shown in Figures 3 and 4. The coatings were

Key to treatment

1. Natural wood—no treatment.
2. One coat of boiled linseed oil and gasoline (baked) plus filler plus two coats of 20-B varnish.
3. Filler plus two coats of 20-A varnish and calcium silicate (baked) plus one coat of 20-A varnish.
4. Filler plus three coats 5-G varnish with barytes powder rubbed in.
5. Filler plus three coats of 5-H varnish.
6. Filler plus three coats 5-G varnish with aluminum powder rubbed in.
7. Filler plus two coats 20-A varnish, red lead, and zinc borate plus one coat of 20-A varnish.
8. Filler plus two coats 20-A varnish and magnesium oxide (baked) plus one coat of 20-A varnish.
9. Filler plus two coats 16-B varnish plus 1 coat of 20-A varnish.
10. Filler and four coats 12½ per cent 20-A varnish, 12½ per cent turpentine, and 75 per cent barytes.
11. 20-B varnish finished by manufacturer.
12. Filler plus two coats of 20-A varnish, zinc borate, and barytes plus one coat of 20-A varnish.
13. Filler plus two coats 20-A varnish and aluminum silicate (baked) plus one coat of 20-A varnish.
14. Filler plus three coats 50 per cent shellac and 50 per cent barytes.
15. Filler plus two coats of 20-A varnish and orange mineral plus one coat of 20-A varnish.
16. Filler plus three coats of 5-L varnish.
17. Filler plus two coats 86 per cent 20-A varnish and 14 per cent barytes (baked) plus one coat of 20-A varnish.
18. Filler plus two coats 20-A varnish and red lead (baked) plus one coat of 20-A varnish.
19. Filler plus two coats 20-A varnish and zinc oxide plus one coat of 20-A varnish.
20. Filler plus two coats 20-A varnish and orange mineral (baked) plus one coat of 20-A varnish.
21. Filler plus two coats 20-A varnish and copper sulphate (baked) plus one coat of 20-A varnish.
22. Filler plus two coats 20-A varnish and red lead plus one coat of 20-A varnish.
23. Filler plus two coats of 20-A varnish and zinc borate (baked) plus one coat of 20-A varnish.
24. Filler plus two coats 75 per cent 20-A varnish and 25 per cent barytes (baked) plus one coat of 20-A varnish.
25. Filler plus two coats 20-A varnish and zinc oxide (baked) plus one coat 20-A varnish.
26. Filler plus two coats white lead and lamp black plus one coat rubbing varnish plus four coats of 20-A varnish.
27. Filler plus two coats 20-A varnish and calcium carbonate (baked) plus one coat of 20-A varnish.
28. Filler plus two coats 67 per cent 20-A varnish and 33 per cent barytes (baked) plus one coat of 20-A varnish.
29. Filler plus two coats 20-A varnish, white lead, and calcium carbonate plus one coat of 20-A varnish.
30. Filler plus three coats of 52-B varnish (black).
31. Filler plus two coats 20-A varnish, red lead, and red oxide plus one coat of 20-A varnish.
32. Filler plus three coats of 5-K varnish.
33. Filler plus two coats 20-A varnish and precipitated barium sulphate plus one coat of 20-A varnish.
34. Filler plus three coats of 44-A varnish.
35. Filler plus two thick coats 20-A varnish and zinc oxide.
36. Filler plus three coats of 52-A varnish (black).
37. Filler plus one coat boiled linseed oil and one-third gasoline plus two coats 20-B varnish plus two coats of 5-E varnish.
38. Filler plus two coats 20-A varnish and lead sulphate plus one coat 20-A varnish.
39. Filler plus two coats 20-A varnish and 50 per cent barytes (baked) plus one coat 20-A varnish.
40. Filler plus two coats 20-B varnish plus two coats of 5-E varnish.
41. Filler plus one coat of 1-D varnish plus three coats of 1-C varnish.
42. Filler plus two coats 20-A varnish and aluminum powder mixed (baked) plus one coat of 20-A varnish.
43. Filler plus two coats 20-A varnish, barytes, zinc oxide plus one coat 20-A varnish.
44. Filler plus two coats 20-A varnish and white lead (baked) plus one coat 20-A varnish.
45. Filler plus two coats 20-B varnish and 20-A varnish mixture plus one coat 20-A varnish.
46. Filler plus two coats 20-A varnish white lead and barytes plus one coat 20-A varnish.
47. Filler plus two coats 20-A varnish, copper bronze, red lead, and barytes plus one coat 20-A varnish.
48. Filler plus two coats of 52-A varnish plus one coat 52-B varnish (black).
49. Filler plus 5-E varnish undercoat plus two coats 5-E varnish with aluminum powder rubbed in plus two coats of 5-E varnish.
50. Filler plus two coats 20-A varnish and ground glass (baked) plus one coat 20-A varnish.
51. Filler plus two coats 20-A varnish and white lead plus one coat of 20-A varnish.
52. Filler plus two coats 14 per cent 20-A varnish and 86 per cent barytes (thinned with turpentine) (baked).
53. Filler plus four coats 25 per cent 20-A varnish and 75 per cent barytes (thinned with turpentine).
54. Filler plus three coats 50 per cent 20-A varnish and 50 per cent barytes.
55. Filler plus two coats 20-A varnish and powdered quartz plus one coat 20-A varnish.
56. Filler plus 5-E varnish undercoat plus two coats 5-E varnish with barytes powder rubbed in plus two coats 5-E varnish.
57. Filler plus two coats 20-A varnish, red oxide, and barytes plus one coat 20-A varnish.
58. Filler plus three coats 50 per cent 2-A varnish and 50 per cent barytes (baked) plus one coat of 2-A varnish.
59. Filler plus two coats 20-A varnish and barytes plus one coat of 20-A varnish.
60. Filler plus four coats 20-A varnish and graphite.
61. Filler plus two coats 33 per cent 20-A varnish and 67 per cent barytes (baked) plus one coat 20-A varnish.
62. Filler plus two coats 20-A varnish and barytes (baked) plus one coat 20-A varnish.
63. Filler plus two coats 25 per cent 20-A varnish and 75 per cent barytes (baked) plus one coat 20-A varnish.
64. Filler plus two coats shellac and aluminum powder plus one coat 5-G varnish.
65. Filler plus two coats 25 per cent 20-A varnish and 75 per cent barytes.
66. Filler plus four coats 25 per cent 2-A varnish and 75 per cent barytes plus three coats of 2-A varnish.

applied by brushing, except in cases where the pigment was dusted on to the almost-dry coat and rubbed in, which are noted in Figure 3. When oven drying or "baking" was employed the freshly applied coat was allowed to air-dry overnight and then put in an oven and heated for four hours at 115° F. and a low relative humidity. Blistering was more likely to occur if the freshly applied coats were put in the oven immediately. A final coat of clear spar varnish was usually applied over the enamels.

The results, which are given in Figures 3 and 4, show that the addition of pigments increased materially the resistance to the passage of

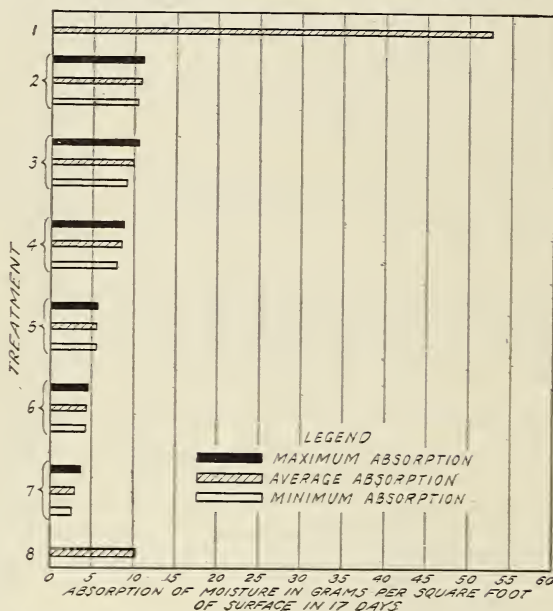


FIGURE 4.—Relative effectiveness of different proportions of barytes in varnish in preventing the absorption of moisture by wood when exposed for 17 days to a relative humidity of 95 to 100 per cent

Key to treatment

1. Natural wood—no treatment.
2. Filler plus two coats of 86 per cent 20-A varnish and 14 per cent barytes plus one coat of 20-A varnish (baked).
3. Filler plus two coats of 75 per cent 20-A varnish and 25 per cent barytes plus one coat of 20-A varnish (baked).
4. Filler plus two coats of 67 per cent 20-A varnish and 33 per cent barytes plus one coat of 20-A varnish (baked).
5. Filler plus two coats of 50 per cent 20-A varnish and 50 per cent barytes plus one coat of 20-A varnish (baked).
6. Filler plus two coats of 33 per cent 20-A varnish and 67 per cent barytes plus one coat of 20-A varnish (baked).
7. Filler plus two coats of 25 per cent 20-A varnish and 75 per cent barytes plus one coat of 20-A varnish (baked).
8. Filler plus three coats of 20-A varnish.

moisture. The effect of increasing the proportion of pigment in the enamel is evident in Figure 4. A mixture of 50 per cent varnish and 50 per cent barytes allowed only about one-half as much absorption of moisture as the clear varnish. Higher proportions of barytes retarded moisture still more, but they became increasingly difficult to apply satisfactorily. The barytes had little opacity, and the 50 per cent mixture was practically transparent. The study did not include a wide variety of enamels and barely touched upon the work that might be done in this field.

CELLULOSE LACQUERS

Five cellulose lacquers furnished by one manufacturer were tried. Brushing was not practicable, so they were applied by dipping. Two specimens were coated with each lacquer, three coats but no filler being used. The finishing procedure was the same as that employed in applying the dipped and air-dried varnish coatings. The moisture absorptions, after exposure to high relative humidities for 17 days were within the range shown in Table 4 for varnishes. The lacquers showed considerable differences among themselves but no general superiority or inferiority to the varnishes. However, the varnishes tested would probably retain their effectiveness longer under outdoor conditions than the lacquers since they withstand

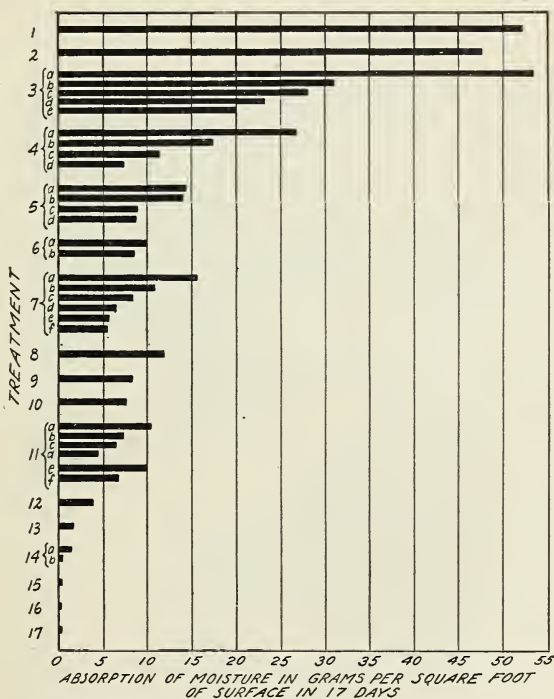


FIGURE 5.—The relative effectiveness of different materials and methods of treatment in preventing the absorption of moisture by wood when exposed for 17 days to a relative humidity of 95 to 100 per cent

(For key to treatment see page 14)

outdoor exposure better than the lacquers when used on wood. The constant improvement in lacquers, however, may remove this distinction in the course of time.

MISCELLANEOUS COATINGS AND TREATMENTS

In addition to the metal leaf, varnish, and other coatings previously discussed, various coatings, treatments, and combinations were tried, none of which proved to have exceptional moisture-excluding properties. Comparisons are given in Figure 5, which is a general summary of the coatings worked with in the war-time experiments.

An important fact shown in Figure 5 is the low effectiveness of five coats of linseed oil followed by two coats of prepared wax. This was the standard finish for airplane propellers at the time and was supposed to be quite effective against moisture changes.

POSTWAR EXPERIMENTS

In considering the results of the moisture-proofing studies started during the World War, it became apparent that additional information must be obtained upon the ability of various coatings and treatments to retain their effectiveness over a long period of time. High effectiveness in excluding moisture from wood has only a limited value unless the coating can stand up for a practical length of time under ordinary exposure conditions. A system of testing was devised, therefore, in which the finished specimens were put through the following cycle of exposures: (1) Conditioning room two weeks (relative humidity about 60 per cent, temperature 80° F.); (2) process of coating; (3) conditioning room two weeks; (4) high humidity room two weeks (95 to 100 per cent relative humidity, temperature 80°); (5) conditioning room two weeks; and (6) weather exposure six weeks. Steps 3 to 6 were repeated until the coating showed marked deterioration.

Step 1 in this cycle was for the purpose of bringing the wood to a constant moisture content of about 11 per cent, before starting the experiment. The supply of uncoated panels was kept stored in the room with a relative humidity of 60 per cent while waiting to be used. The 2-week conditioning period of step 1 was therefore a minimum,

Key to treatment

1. Natural wood—no treatment.
2. Five coats of linseed oil plus two coats of wax.
3. Impregnation treatments:
 - (a) Linseed oil (soaking).
 - (b) Paraffin and gasoline (vacuum and pressure).
 - (c) Beeswax (vacuum and pressure).
 - (d) Spar varnish (vacuum and pressure).
 - (e) Cellulose varnish (vacuum and pressure).
4. Filler plus three coats of spar varnish:
 - (a) Poorest of 43 varnishes tested.
 - (b) Average of 43 varnishes tested.
 - (c) Average of 10 best varnishes tested.
 - (d) Best varnish tested.
5. Forced drying (filler and 3 coats):
 - (a) Average of 23 varnishes (room dried).
 - (b) Same varnishes (dried at 110° F.).
 - (c) Average of five enamels (room dried).
 - (d) Same enamels (dried at 110° F.).
6. Brushed versus dipped coatings:
 - (a) Filler plus three brushed coats (average of seven varnishes).
 - (b) Filler plus three dipped coats (average of same varnishes).
7. Filler plus different numbers of coatings:
 - (a) Two brushed coats.
 - (b) Four brushed coats.
 - (c) Six brushed coats.
 - (d) Eight brushed coats.
 - (e) Ten brushed coats.
 - (f) Twelve brushed coats.
8. Three coats of cellulose varnish.
9. Filler plus three coats of orange shellac.
10. Filler plus three coats of rubbing varnish.
11. Enamels—filler plus:
 - (a) Two coats enamel (red-lead pigment) plus varnish.
 - (b) Two coats enamel (aluminum powder) plus varnish.
 - (c) Two coats enamel (white-lead pigment) plus varnish.
 - (d) Two coats enamel (barytes pigment) plus varnish.
 - (e) Three coats commercial enamel (average of 11 brands).
 - (f) Three coats commercial enamel (best brand).
12. Filler plus three coats of shellac and aluminum powder.
13. Five coats of bakelite plus five coats of varnish.
14. Metal leaf coatings—filler plus shellac or varnish under coat plus varnish size plus aluminum leaf plus two coats of varnish, shellac, or enamel:
 - (a) Average of all types.
 - (b) Best type.
15. Sprayed with copper or aluminum and coated with three coats of varnish.
16. Electroplated with copper.
17. Vulcanized-rubber coating (one small specimen tested).

since the panels were often stored in the room for several months before being used.

The coating of the specimens at the Forest Products Laboratory was done in a room at ordinary temperatures and relative humidities. Frequently specimens were sent away to be coated by companies or individuals interested in having a test made. In such cases the laboratory had no control over the conditions during the finishing period. In either case, after the finish or treatment had dried, the panels were returned to the conditioning room at 60 per cent relative humidity for a 2-week period in order to insure their being very close to their original moisture content. (Fig. 6.)

In step 4 the panels were exposed for two weeks to air that was practically saturated with water. Weights taken just before and just after this exposure period showed how much moisture the coating had allowed to pass into the wood. The panels were then returned to

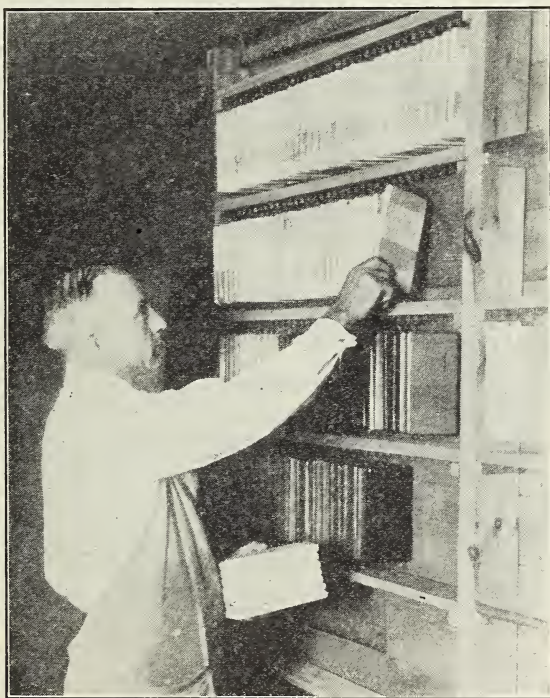


FIGURE 6.—Coated panels in the conditioning room kept at 60 per cent relative humidity

the conditioning room at 60 per cent relative humidity for two weeks in order to dry out again.

In step 6 the panels were exposed to the weather for six weeks on racks. The racks were on a flat roof, and the panels hung in such a manner that they faced south and were at an angle of 60° to the horizontal. (Fig. 7.) The finish was thus subjected to the deteriorating effect of the weather, which was very rapid on some types of coatings and slow on others. After step 6, the panels were repeatedly subjected to steps 3 to 6, inclusive, as long as the coatings remained in good condition. As the effectiveness of the coating decreased with repeated weather exposure the effect was usually shown by the con-

tinually increasing absorptions in step 4. In some cases, however, the inspector removed panels from test on account of flaking, checking or other visible deterioration before much effect on moisture absorption was apparent.

On account of the method of exposure and the fact that the same side of the panel was exposed to the weather each time, the weathering took effect principally on one face of the panel. In step 4, however, where the effect of high humidity on the weathered panel was measured, all faces of the panel were exposed equally to the high relative humidity, and the rate of moisture absorption, after the coating began to deteriorate, was undoubtedly greater on the weathered side of the panel than on the back. If, during the weather exposure, the weather could have acted upon all sides of the panels instead of only one

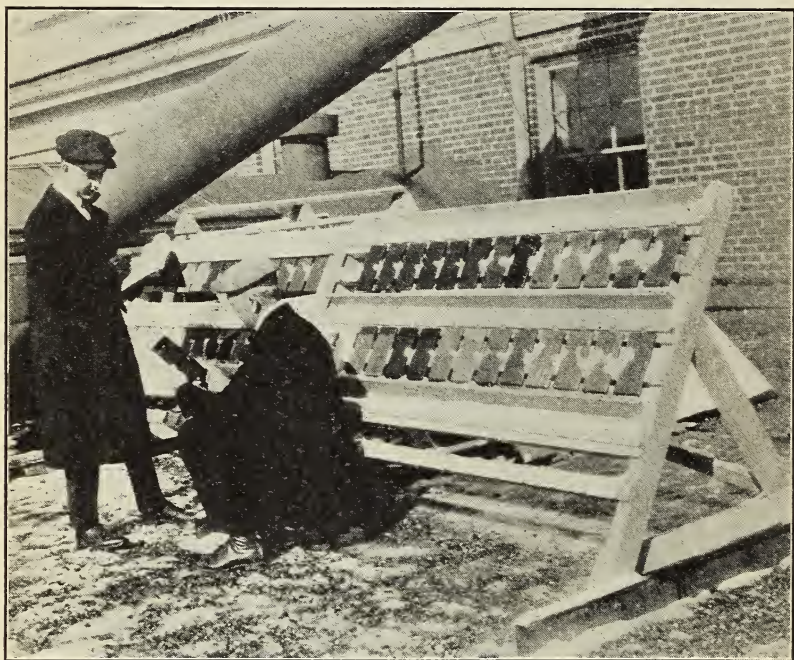


FIGURE 7.—Examining panels on the weather-exposure racks

side, the apparent durability of the coating would probably have been lower. On the other hand, exposure at an angle of 45° to the horizontal facing south has been found to deteriorate paint coatings one and one-half to two times as fast as vertical exposure. Exposure at 60° to the horizontal would be intermediate between vertical exposure and 45° exposure so that the method of weather exposure used here (as it affects subsequent absorption of moisture in the high humidity test) may be nearly equivalent to having the weather acting on all sides of a vertically hung panel. In any event, the results given here are comparative since the same procedure was followed with all panels.

RESULTS OF POSTWAR HUMIDITY AND WEATHERING TESTS

About 2,000 panels have been exposed thus far in tests using the foregoing procedure. These panels include practically all types of

coatings or treatments that are in use or were thought at the time to have possibilities. The following rough classification shows the range in the character of finishes tested, but there were many combination treatments representing two or more groups: (1) Coatings containing metal leaf or powder; (2) oil paints; (3) cold-water paints; (4) asphaltic, bituminous, pitch, and similar paints; (5) oil varnishes; (6) shellac and spirit varnishes; (7) enamels; (8) lacquers and lacquer enamels; (9) primers and fillers, (10) rubber-cement and latex coatings; (11) coatings of solid sheet materials; (12) oils and greases; (13) waxes; (14) glues; and (15) miscellaneous, unclassified, or unknown.

In considering the results obtained in the weathering tests it has been arbitrarily assumed that any coating or treatment was not worthy of much consideration for the protection of wood outdoors if it failed by cracking, peeling, wear, or otherwise in less than 52 weeks of outdoor exposure, or if it allowed an average moisture absorption of more than 15 grams persquare foot in two weeks in the high relative humidity test. The experiments are being carried on continuously, and a considerable number of coatings have not been under test for a sufficient length of time to determine whether they can meet this specification. An appreciable number that have been under test long enough, however, qualify easily, and some of them have greatly exceeded the limits mentioned above, as shown in Tables 6 and 7.

TABLE 6.—*Summary of data from weathering tests on the more effective coatings*

Character of coating	Number of coats and their composition	Total weather exposure ¹ (weeks)	Absorptions in high relative humidity test (grams per square foot)		
			Average	Maximum	Minimum
Coatings containing aluminum leaf.	3 coats aluminum leaf interspersed in 6 brush coats spar varnish.	198	7.55	25.22	0.76
	2 coats aluminum leaf interspersed in 5 brush coats spar varnish.	120	10.60	23.20	.76
	3 coats aluminum leaf interspersed in 6 brush coats white-lead paint.	198+	1.35	3.53	.29
	2 coats aluminum leaf interspersed in 5 brush coats white-lead paint.	198+	2.60	9.14	.48
	1 coat aluminum leaf interspersed in 4 brush coats white-lead paint.	198+	13.44	34.95	1.52
	3 brush coats spar varnish containing 9.1 per cent aluminum powder.	96	10.69	23.31	4.38
	2 brush coats spar varnish containing 16.6 per cent aluminum powder.	78	10.03	17.89	4.76
	3 brush coats spar varnish containing 16.6 per cent aluminum powder.	120	4.48	6.76	.67
	3 brush coats spar varnish containing 20 per cent unpolished aluminum powder.	132+	12.03	28.75	4.57
	3 brush coats spar varnish containing 20 per cent polished aluminum powder.	114	8.57	14.48	4.76
Miscellaneous coatings containing aluminum powder.	3 brush coats spar varnish containing 33 to 44 per cent aluminum powder.	84+	14.14	29.51	6.28
	3 brush coats spar varnish containing 44 per cent aluminum powder.	84+	8.58	17.15	4.95
	3 brush coats spar varnish containing 37 to 44 per cent aluminum powder.	60	7.10	9.14	5.52
	3 brush coats spar varnish containing 33 to 37 per cent aluminum powder.	60	5.42	7.04	4.28
	3 brush coats proprietary aluminum paint.	60+	8.27	12.38	5.33
	3 brush coats proprietary bituminous paint with 10 per cent aluminum powder added.	72	8.95	17.71	.86
	2 brush coats, same paint, with 20 per cent aluminum powder added.	54	9.20	19.33	1.24
	3 brush coats, same paint, with 20 per cent aluminum powder added.	54	4.03	10.47	.38
	3 brush coats mixture of ½ gallon proprietary asphalt paint, ½ gallon naphtha, and 1½ pounds aluminum powder.	60+	9.34	16.66	5.42

¹ Panels marked plus are still in the test.

TABLE 6.—*Summary of data from weathering tests on the more effective coatings—*
Continued

Character of coating	Number of coats and their composition	Total weather exposure (weeks)	Absorptions in high relative humidity test (grams per square foot)		
			Average	Maximum	Minimum
Lead paints with and without aluminum powder.	3 brush coats paint containing 27.3 per cent boiled oil, 72.7 per cent orange mineral.	114+	² 17.47	27.90	6.09
	3 brush coats paint containing 20 per cent boiled oil, 80 per cent orange mineral.	114+	11.98	24.65	7.52
	3 brush coats paint containing 16.6 per cent boiled oil, 83.4 per cent orange mineral.	114	9.55	20.38	5.04
	3 brush coats paint containing 26.3 per cent boiled oil, 69.9 per cent orange mineral, and 3.8 per cent aluminum powder.	114+	6.01	12.38	3.52
	3 brush coats paint containing 19.3 per cent boiled oil, 76.9 per cent orange mineral, and 3.8 per cent aluminum powder.	114+	5.27	10.95	3.05
	3 brush coats paint containing 16 per cent boiled oil, 80.2 per cent orange mineral, and 3.8 per cent aluminum powder.	114+	4.28	6.85	2.47
	3 brush coats paint containing 27.3 per cent boiled oil, 72.7 per cent red lead.	102	² 16.28	24.28	10.57
	3 brush coats paint containing 20 per cent boiled oil, 80 per cent red lead.	114+	7.21	14.38	4.09
	3 brush coats paint containing 16.6 per cent boiled oil, 83.4 per cent red lead.	114+	8.14	16.95	5.14
	3 brush coats paint containing 26.3 per cent boiled oil, 69.9 per cent red lead, and 3.8 per cent aluminum powder.	114+	6.23	13.90	3.90
	3 brush coats paint containing 19.3 per cent boiled oil, 76.9 per cent red lead, and 3.8 per cent aluminum powder.	114+	5.73	12.48	3.43
	3 brush coats paint containing 16 per cent boiled oil, 80.2 per cent red lead, and 3.8 per cent aluminum powder.	114+	4.63	9.14	2.76
	2 brush coats white-lead paint with 5 per cent aluminum powder added.	138+	10.64	17.33	.86
	3 brush coats white-lead paint with 5 per cent aluminum powder added.	138+	7.43	19.13	.38
	2 brush coats white-lead paint with 10 per cent aluminum powder added.	138+	6.84	12.95	.48
	3 brush coats white-lead paint with 10 per cent aluminum powder added.	138+	4.63	9.71	.19
	3 brush coats proprietary lead-suboxide paint No. 1 and No. 3.	78+	5.89	7.62	4.00
	3 brush coats proprietary lead-suboxide paint No. 3.	72+	5.68	7.23	3.71
	1 brush coat proprietary lead-suboxide paint No. 1 plus 2 coats white lead.	66+	8.45	11.71	5.52
	2 brush coats proprietary lead-suboxide paint.	84	10.85	19.60	6.56
	3 brush coats proprietary lead-suboxide paint.	90	7.11	17.15	2.67
	3 brush coats pearl-gray paint.	186	10.57	16.38	6.66
	3 brush coats stone-colored paint.	120	14.43	20.75	10.10
	3 brush coats pink paint.	126	13.08	18.66	8.00
	3 brush coats terra cotta-colored paint.	126	14.90	20.28	9.80
	3 brush coats white paint.	150	14.70	28.95	7.90
	3 brush coats robin's-egg-blue paint.	90	14.42	18.37	11.71
	3 brush coats azure-blue paint.	90	12.43	16.48	8.00
	3 brush coats sky-blue paint.	120	11.84	18.46	6.38
	3 brush coats apple-green paint.	120	14.14	19.23	8.38
	3 brush coats sage-green paint.	120	13.09	17.15	7.61
Mixed pigment prepared housepaints.	3 brush coats gray tint paint.	120	12.44	20.18	7.42
	3 brush coats silver-gray paint.	132	13.11	18.47	7.61
	3 brush coats ivory paint.	144	9.18	14.66	4.85
	3 brush coats cream paint.	186	12.70	19.80	7.24
	3 brush coats light flesh-colored paint.	180	9.95	15.52	5.52
	3 brush coats yellow paint.	198+	10.99	17.15	6.28
	3 brush coats reddish-spruce paint.	168	12.60	17.62	6.66
	3 brush coats fawn-colored paint.	132	12.35	17.62	6.95
	3 brush coats ochre brown paint.	120	13.22	17.72	7.42
	3 brush coats pale blue paint.	90	11.37	16.00	7.62

² Not highly effective but included for comparison.

TABLE 6.—*Summary of data from weathering tests on the more effective coatings—*
Continued

Character of coating	Number of coats and their composition	Total weather exposure (weeks)	Absorptions in high relative humidity test (grams per square foot)		
			Average	Maximum	Maximum
Miscellaneous coatings.	Artificial resin varnish applied by manufacturer.....	78+	3.93	11.71	1.05
	do.....	78+	2.24	6.38	.76
	do.....	78+	6.25	29.41	1.14
	2 brush coats zinc dust-zinc oxide prepared paint.....	54	9.89	13.24	7.14
	3 brush coats zinc dust-zinc oxide prepared paint.....	84	6.04	9.14	4.00
	3 brush coats of a proprietary cement paint.....	114	7.54	14.72	4.28
	3 brush coats of a proprietary asphalt paint (red)....	84	11.14	17.82	4.19
	3 brush coats of a proprietary asphalt paint (black)....	60+	6.90	9.52	4.85
	3 brush coats of a proprietary roof cement.....	150	7.68	14.10	3.90
	do.....	126	6.04	13.50	1.05
	3 brush coats of a proprietary asphalt roof paint.....	54	5.00	10.00	.38
	3 brush coats of a proprietary black metal paint.....	54	8.83	18.37	1.81
	3 dip coats of a proprietary black asphaltic paint.....	198+	8.33	14.00	2.67
	3 brush coats of a proprietary black asphaltic paint.....	54	7.11	12.85	3.73
	Baked enamel applied by manufacturer.....	84	5.92	7.52	3.33
	do.....	126	10.53	15.33	1.22
	1 coat special coating, 3 coats white-lead paint....	60+	12.52	19.42	8.18
	3 coats white-lead paint, 1 coat special coating....	60+	6.67	11.23	.48
	3 coats white-lead paint, 2 coats special coating....	60+	6.28	9.90	3.51
	3 coats white-lead paint, 3 coats special coating....	60+	4.93	9.72	.86

Coatings containing metal leaf or powder, oil-paint coatings, and combinations of the two comprised about three-fourths of those that met the above specification. Most of the remaining ones that passed were either in Group 4 (asphaltic, bituminous, pitch, and similar paints) or Group 5 (oil varnishes). Thus far only one material has qualified in Group 7 (enamels). No coating or treatment has yet qualified in Groups 3 (cold-water paints), 6 (shellac and spirit varnishes), 8 (lacquers and lacquer enamels), 9 (primers and fillers), 10 (rubber-cement and latex coatings), 11 (coatings of solid sheet materials), 12 (oils and greases), 13 (waxes), 14 (glues), or 15 (miscellaneous).

The possibilities have not been exhausted in any of the groups, but it seems very unlikely that coatings combining high effectiveness and high weather resistance will be found in Groups 3, 6, 8, 12, or 14. Primers and fillers of the now commonly used types are not promising, but there is always the possibility of finding new materials of greater suitability in this group. Rubber-cement and latex coatings or coatings depending upon rubber in some form may yet be developed that will be effective. Coatings of solid sheet materials are not very practical for most uses even if effective ones are ultimately found. It is obvious that a coating of sheet metal with all joints perfectly soldered should entirely prevent moisture changes, but there is little practical use for wood so encased. Table 7 lists the coatings that had average absorptions of less than 6 grams per square foot after exposure to the weather for more than 52 weeks.

TABLE 7.—*Character of coatings on panels with average absorptions of less than 6 grams per square foot of surface after 52 weeks or longer exposure in the high humidity test*

Number of coats and character of coating	Total weather exposure ¹ (weeks)	Absorptions in high humidity test (grams per square foot)		
		Average	Maximum	Minimum
3 coats aluminum leaf interspersed in 6 brush coats white-lead paint...	+198	1.35	3.53	0.29
2 coats aluminum leaf interspersed in 5 brush coats white-lead paint...	+198	2.60	9.14	.48
Artificial resin varnish applied by manufacturer.....	+78	2.24	6.38	.76
Do.....	+78	3.93	11.71	1.05
3 brush coats paint containing 16 per cent boiled oil, 80.2 per cent orange mineral, and 3.8 per cent aluminum powder.....	+114	4.28	6.85	2.47
3 brush coats white-lead paint with 10 per cent aluminum powder added.....	+138	4.63	9.71	.19
3 brush coats paint containing 16 per cent boiled oil, 80.2 per cent red lead, and 3.8 per cent aluminum powder.....	+114	4.63	9.14	2.76
3 brush coats spar varnish containing 16.6 per cent aluminum powder.....	120	4.48	6.76	.67
3 brush coats proprietary bituminous paint with 20 per cent aluminum powder added.....	54	4.03	10.47	.38
3 brush coats white-lead paint and 3 brush coats special coating.....	+60	4.93	9.72	.86
3 brush coats proprietary asphalt roof paint.....	54	5.00	10.00	.38
3 brush coats paint containing 19.3 per cent boiled oil, 76.9 per cent orange mineral, and 3.8 per cent aluminum powder.....	+114	5.27	10.95	3.05
3 brush coats spar varnish containing 33 to 37 per cent aluminum powder.....	60	5.42	7.04	4.28
3 brush coats paint containing 19.3 per cent boiled oil, 76.9 per cent red lead, and 3.8 per cent aluminum powder.....	+ 114	5.73	12.48	3.43
3 brush coats proprietary lead-suboxide paint No. 3.....	+72	5.68	7.23	3.71
3 brush coats proprietary lead-suboxide paint No. 1 and No. 3.....	+78	5.89	7.62	4.00
Baked enamel applied by manufacturer.....	84	5.92	7.52	3.33

¹ Panels marked plus are still in the test.

For high effectiveness and great weather resistance the white-lead aluminum leaf coatings proved far superior to any other coatings tested. The two coatings of this type shown in Table 7 are not practical for ordinary purposes, however, because aluminum leaf is not convenient to apply and because of the large number of coats employed.

Next, in effectiveness, were two artificial resin varnishes, which were applied by the manufacturer. Although the composition of the varnishes was not disclosed, the resin used was probably of the aldehyde-condensation type, like bakelite or condensite. The uncoated panels were sent by the Forest Products Laboratory to the varnish manufacturer, who coated and returned them. No information is available on the number of coats or the method of application.

In Table 8 are given the individual absorption test data obtained to date on the two artificial resin varnishes referred to (lines 1 and 2), together with similar data on other artificial resin varnishes under test and on several spar varnishes. It may be noted that the artificial resin varnishes gave considerably better results than the spar varnishes and generally withstood weathering better. Since so little information is available on the amount of artificial resin varnish applied to the various panels by the manufacturers, and the conditions of application and subsequent handling are not known to the Forest Products Laboratory, it is unsafe to draw positive conclusions from this comparison with ordinary spar varnishes. However, on the basis of available data, the artificial resin varnishes deserve further careful study.

TABLE 8.—*Effect of repeated weather exposure on moisture-excluding effectiveness of various varnishes*

Kind of varnish		Number of coats	Amounts of moisture absorbed in high relative humidity test after successive exposures to the weather of—												Number of weeks in test	Absorptions in high relative humidity test					
			0 week	6 weeks	12 weeks	18 weeks	24 weeks	30 weeks	36 weeks	42 weeks	48 weeks	54 weeks	60 weeks	72 weeks		78 weeks	Average	Maximum	Minimum		
Artificial resin	Unknown	1.43	1.81	1.05	1.33	2.28	2.48	3.43	4.00	4.10	4.00	---	---	---	5.04	8.38	11.71	78+	3.93	11.71	1.05
	Do	1.05	1.71	1.14	1.76	1.62	1.76	1.52	1.52	2.67	1.81	---	---	---	2.47	4.47	6.38	78+	2.24	6.38	.76
	Do	1.14	2.00	1.33	1.43	2.57	2.95	4.19	5.80	5.71	6.09	---	---	---	6.48	12.10	29.41	78+	6.25	29.41	1.14
	3 spray	4.85	2.86	2.00	2.95	5.24	3.43	3.24	5.42	---	---	---	---	---	---	---	---	42+	3.75	5.42	2.00
	Do	10.48	6.76	7.33	8.09	11.80	8.18	6.06	10.28	---	---	---	---	---	---	---	---	42+	8.70	11.80	6.66
	Do	7.04	---	---	7.71	7.80	4.66	4.66	6.57	---	---	---	---	---	---	---	---	42+	4.47	5.93	7.80
	Do	4.67	2.86	3.72	4.47	6.66	6.09	8.85	14.85	---	---	---	---	---	---	---	---	42+	6.52	14.85	4.47
	Do	6.76	7.90	7.61	11.80	10.42	---	---	---	---	---	---	---	---	---	---	---	24	10.70	19.42	6.76
	Do	5.24	3.62	4.38	3.62	7.33	4.47	5.71	7.65	---	---	---	---	---	---	---	---	42+	2.25	7.65	3.62
	Do	3.52	1.81	2.76	2.67	4.38	2.76	2.38	3.23	---	---	---	---	---	---	---	---	42+	2.94	4.38	1.81
	3 brush	5.42	4.57	4.85	5.14	6.66	11.05	---	---	---	---	---	---	---	---	---	---	30	6.28	11.05	4.57
	Do	3.52	3.43	4.66	3.90	6.66	---	16.28	---	---	---	---	---	---	---	---	---	36+	6.41	16.28	3.43
Proprietary spar	Do	7.33	9.33	11.90	---	---	---	---	---	---	---	---	---	---	---	---	---	12	9.52	11.90	7.33
	Do	10.10	7.90	8.38	---	7.80	12.85	14.10	---	---	---	---	---	---	---	---	---	36+	10.10	14.10	7.80
	Do	6.09	5.42	7.14	---	10.38	17.42	21.21	---	---	---	---	---	---	---	---	---	30+	11.28	21.21	5.42
	Do	3.24	4.95	6.09	---	9.04	14.95	20.00	---	---	---	---	---	---	---	---	---	36+	10.05	20.00	4.95
	Do	21.30	26.48	22.65	21.70	27.80	31.80	25.22	---	---	---	---	---	---	---	---	---	42	26.14	31.80	21.70
	Do	25.51	32.00	38.75	21.70	27.70	---	---	---	---	---	---	---	---	---	---	---	24	33.49	42.00	25.51
	Do	44.48	44.48	47.60	16.86	44.48	44.48	44.48	---	---	---	---	---	---	---	---	---	18	38.35	47.60	16.86
	Do	32.84	39.32	43.90	14.00	43.05	---	---	---	---	---	---	---	---	---	---	---	24	34.62	43.90	14.00
	Do	34.10	37.42	44.25	13.81	50.10	---	---	---	---	---	---	---	---	---	---	---	24	35.93	50.10	13.81
	Do	20.10	21.60	37.90	17.43	18.00	---	---	---	---	---	---	---	---	---	---	---	48	24.73	37.90	17.43
	Do	25.70	24.95	29.80	31.80	23.31	30.65	26.10	38.65	---	---	---	---	---	---	---	---	42	28.87	38.65	23.31
	Do	19.90	24.38	31.70	23.70	36.00	37.70	---	---	---	---	---	---	---	---	---	---	30	28.89	37.70	19.90
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93	25.12	---	---	---	---	---	---	---	---	---	---	30	18.72	25.12	13.34	
Do	13.34	13.43	20.09	19.42	20.93																

1 Plus mark indicates panels still in the test.

Lead-pigment paints gave some very interesting and effective results, as shown in detail in Table 9. In the case of both orange mineral and red lead, the moisture-excluding effectiveness increased notably as the percentage of pigment in the paint increased. The addition of aluminum powder effected further improvement and with the high pigment paints gave excellent results. In this connection it is of interest to refer to Figure 4, which shows how increasing effectiveness was obtained by increasing the percentage of pigment in a spar-varnish enamel. A similar comparison showing the effect of increasing percentages of pigment unfortunately was not made with white lead, but the white lead-aluminum powder mixtures tried proved very effective.

TABLE 9.—*Effect of repeated weather exposure on moisture-excluding effectiveness of various lead paints, with and without aluminum powder*

Character of coating	Num- ber of coats	Amounts of moisture absorbed in high relative humidity test after successive exposures to the weather of—														
		0 week	6 weeks	12 weeks	18 weeks	24 weeks	30 weeks	36 weeks	42 weeks	48 weeks	54 weeks	60 weeks	66 weeks	72 weeks	78 weeks	
{ 27.3 per cent boiled oil ----- 72.7 per cent orange mineral 20 per cent boiled oil 80 per cent orange mineral 16.6 per cent boiled oil 83.4 per cent orange mineral 26.3 per cent boiled oil 69.9 per cent orange mineral 19.3 per cent aluminum powder 49.3 per cent boiled oil 76.9 per cent orange mineral 3.8 per cent aluminum powder 30.2 per cent aluminum powder 16 per cent boiled oil 27.3 per cent orange mineral 72.7 per cent red lead 20 per cent boiled oil 80 per cent red lead 16.6 per cent boiled oil 83.4 per cent red lead 26.3 per cent boiled oil 69.9 per cent red lead 19.3 per cent aluminum powder 49.3 per cent boiled oil 76.9 per cent red lead 3.8 per cent aluminum powder 30.2 per cent red lead 16 per cent boiled oil 27.3 per cent aluminum powder Do White lead paint plus 5 per cent aluminum powder Do White lead paint plus 10 per cent aluminum powder Do Proprietary lead suboxide paint No. 1 Proprietary lead suboxide paint No. 3	3	26.29	17.52	18.20	13.23	10.95	13.90	10.19	11.43	6.09	10.10	14.00	15.71	20.47	23.90	
	3	19.60	12.57	13.14	9.33	7.52	10.28	7.71	7.80	12.00	6.38	8.56	7.80	8.86	10.95	
	3	16.20	10.48	10.57	7.52	6.66	7.52	6.28	6.09	5.62	5.04	7.24	6.57	6.85	9.42	
	3	12.38	8.56	8.28	7.04	4.29	6.18	5.62	5.80	4.57	4.57	6.56	6.09	6.00	3.52	
	3	9.71	6.85	6.38	5.62	3.24	4.95	4.66	4.28	3.62	3.71	5.80	4.95	5.04	3.05	
	3	-----	6.85	6.09	5.62	3.24	4.57	4.00	4.47	3.24	4.09	5.71	5.24	4.76	3.24	
	3	24.28	15.80	17.52	13.14	11.05	12.75	10.57	10.85	11.90	10.47	14.95	16.95	18.47	19.90	
	3	14.38	9.04	9.14	7.52	5.24	7.14	5.24	6.00	5.42	4.28	6.09	5.90	5.80	4.09	
	3	14.95	9.14	9.72	7.81	5.62	8.18	5.42	6.38	5.52	9.14	6.28	6.57	5.90	5.14	
	3	13.90	8.66	8.86	7.04	4.85	6.38	5.71	6.10	4.95	4.66	6.94	6.10	5.71	4.09	
{ 19.3 per cent aluminum powder 49.3 per cent boiled oil 76.9 per cent red lead 3.8 per cent aluminum powder 30.2 per cent red lead 16 per cent boiled oil 27.3 per cent aluminum powder Do White lead paint plus 5 per cent aluminum powder Do White lead paint plus 10 per cent aluminum powder Do Proprietary lead suboxide paint No. 1 Proprietary lead suboxide paint No. 3	3	12.48	7.90	8.19	6.76	3.52	5.90	5.14	5.52	4.76	4.38	6.38	5.90	5.14	3.90	
	3	9.14	6.38	6.09	5.52	3.05	4.95	3.81	4.00	3.62	3.52	5.42	4.38	6.95	2.95	
	2	14.95	3.52	18.38	14.19	8.76	6.76	12.38	10.57	10.67	8.38	8.38	10.85	13.42	8.00	
	3	11.24	2.67	13.90	10.67	6.09	5.90	8.95	7.62	8.19	6.09	5.42	6.95	8.95	5.42	
	2	10.57	2.48	12.95	10.38	5.80	4.47	8.95	7.42	7.14	6.00	5.33	7.04	8.94	4.57	
	3	7.71	2.09	9.71	7.90	4.19	3.43	6.85	5.42	5.23	4.66	3.71	4.76	6.09	3.14	
	3	7.62	5.99	6.47	6.66	5.33	6.09	4.86	4.47	4.00	5.90	-----	-----	4.47	7.42	
	3	7.23	5.61	6.76	6.85	5.24	6.09	4.47	3.90	5.42	-----	-----	3.71	7.18	-----	

[Grams per square foot]

TABLE 9.—*Effect of repeated weather exposure on moisture-excluding effectiveness of various lead paints, with and without aluminum powder*—
Continued

Character of coating	Num- ber of coats	Amounts of moisture absorbed in high relative humidity test after successive ex- posures to the weather of—										Absorption in high rela- tive humidity test		
		84 weeks	90 weeks	96 weeks	102 weeks	108 weeks	114 weeks	120 weeks	126 weeks	132 weeks	138 weeks	Aver- age	Maxi- mum	Mini- mum
27.3 per cent boiled oil.....	3	20.10	22.56	27.90	27.02	17.53	22.28	---	---	---	---	17.47	27.90	6.09
72.7 per cent orange mineral.....	3	10.57	11.90	18.00	14.47	17.43	24.65	---	---	---	---	11.98	24.65	6.38
80 per cent boiled oil.....	3	10.18	11.71	15.62	14.95	20.38	6.15	---	---	---	---	9.55	20.38	5.04
83.4 per cent orange mineral.....	3	4.09	4.28	6.47	---	4.29	5.62	---	---	---	---	6.01	12.38	3.52
26.3 per cent boiled oil.....	3	4.28	3.62	6.38	3.05	10.95	5.24	---	---	---	---	5.27	10.95	3.05
69.9 per cent orange mineral.....	3	3.33	2.95	4.76	2.47	2.76	4.00	---	---	---	---	4.28	6.85	2.47
3.8 per cent aluminum powder.....	3	18.18	20.20	22.65	23.40	---	---	---	---	---	---	16.28	24.28	10.47
16 per cent boiled oil.....	3	5.42	5.71	8.28	6.85	8.38	14.20	---	---	---	---	7.21	14.38	4.09
80.2 per cent orange mineral.....	3	5.42	5.90	10.10	8.28	10.48	16.95	---	---	---	---	8.14	16.95	5.14
3.8 per cent aluminum powder.....	3	4.47	4.38	6.85	3.90	---	4.85	---	---	---	---	6.23	13.90	3.90
69.9 per cent red lead.....	3	4.00	3.71	6.09	3.43	---	---	---	---	---	---	5.73	12.48	3.43
19.3 per cent boiled oil.....	3	3.43	3.43	5.14	2.76	3.43	4.57	---	---	---	---	4.63	9.14	2.76
3.8 per cent aluminum powder.....	2	11.61	13.24	14.85	11.90	10.57	2.86	21.62	---	---	---	10.64	18.38	.86
White lead paint plus 5 per cent aluminum powder.....	3	6.75	7.33	8.00	6.00	5.62	2.38	21.52	---	---	---	7.43	19.13	.38
White lead paint plus 10 per cent aluminum powder.....	2	7.23	7.43	8.66	6.76	5.90	2.48	21.43	---	---	---	6.84	12.55	.48
Do.....	3	4.28	4.57	4.76	3.81	3.24	2.19	21.24	---	---	---	4.63	9.71	.19
Proprietary lead suboxide paint No. 1.....	3	---	---	---	---	---	---	---	---	---	---	5.89	7.62	4.00
Proprietary lead suboxide paint No. 3.....	3	---	---	---	---	---	---	---	---	---	---	5.68	7.23	3.71

¹ Plus mark indicates panels still in the test.

² Low value probably caused by too low a relative humidity.

The results in the last two lines of Table 9 were obtained with proprietary paints said to contain a suboxide of lead as a principal ingredient. Four other similar paints from the same manufacturer tested about the same time were not quite so effective, although three of them had average absorptions of less than 15 grams per square foot. (Table 6.) Since no details are available concerning the composition of these paints, the results have only limited usefulness, but they indicate the desirability of further study.

The long life of the paints listed in Table 9 is noteworthy. All but three of them were still in the test after 114 to 138 weeks' exposure, and most of those containing aluminum powder continued to maintain their high effectiveness.

From these experiments it may be concluded that in situations where lead and oil paints are permissible, and under ordinary conditions of use and exposure, a high degree of moisture protection may be obtained from lead-pigment aluminum-powder coatings similar to those of Table 9, provided the coatings are maintained in good condition. It is probable, of course, that such coatings would fail more rapidly and require renewal more often when used on some species of wood than they did on the birch specimens used in these tests. It is also true that for greatest effectiveness it is necessary to apply the coatings on all sides of the wood to be protected.

The possibilities of mixed-pigment paints with aluminum powder added were not studied, but it is reasonable to suppose that with suitable mixtures of this kind results could be obtained similar to those shown in Table 9. The good results shown in Table 6 with the prepared house paints indicate that the addition of aluminum powder in suitable proportions would have provided very effective coatings.

A number of miscellaneous coatings that gave fairly good results are shown in Table 6. Many of them are of the bituminous or asphaltic type, and most of them are of patented or secret composition. It is exceedingly difficult to make recommendations concerning bituminous or asphaltic paints and coatings. Over 50 of them were tested. Twelve of them are included in Table 6. Only two are included in Table 7, and one of these contained aluminum powder.

No way has yet been discovered to tell, except by trial, whether a new paint of this type will prove good or bad. Furthermore, even if a test shows it to be good, there is no assurance that the formula will not be changed in the course of the two or three years required to make the test. Formula changes may be made at any time in such paints on account of changes in prices of the ingredients used or to improve the paint in moisture resistance or in some other respect. About the only way in which much progress can be made in finding the most reliable and effective paints of the asphaltic and bituminous type is to make a long series of tests with paints whose formulæ are known, varying the formulæ to learn the influence and value of each of the principal ingredients.

The results of baked enamel coatings, given in Tables 6 and 7, are the best of four such coatings submitted by one manufacturer. Information is not available as to the character of the material used, the number of coats, or the method of application. The results indicate that it is possible for such coatings to give high protection, but they do not show what particular enamels or methods are neces-

sary. Four other enamels from different manufacturers, when applied by brushing or dipping and then air-dried, gave very poor results. They were low in both moisture resistance and durability.

FIELD-EXPOSURE EXPERIMENT

In order to learn what seasonal fluctuations in moisture content take place in coated and uncoated wood in various locations throughout the United States, sets of panels were sent to 10 stations for frequent weighing and observation. Each set consisted of 9 test panels of spruce and 9 of ash, $\frac{5}{8}$ by 4 by 8 inches in size. Of the 9 panels of each species, 3 were uncoated, 3 were finished by applying a filler plus 3 coats of spar varnish, and 3 were finished by applying a filler plus 1 coat of spar varnish, plus a sizing coat of spar varnish and turpentine, plus 1 coat of aluminum leaf, plus 2 coats of gray enamel. The finishes were applied to all surfaces. The panels were brought to an equilibrium moisture content at 60 per cent relative humidity before finishing and again after the final coats of the finishes had been applied. Sets were then exposed at the following places: San Francisco, Calif.; Carson, Wash.; Priest River, Idaho; Flagstaff, Ariz.; Colorado Springs, Colo.; St. Paul, Minn.; Madison, Wis.; Dayton, Ohio; Valparaiso, Fla.; and Amherst, Mass. At each station the panels were hung under cover in such a manner that they were protected from rain or snow but were freely exposed to outdoor air. In this way they were affected by the variations in atmospheric humidity but not by precipitation. The panels were weighed before shipment and at intervals of about one month during the exposure period of about two and one-third years. The moisture content of each panel was calculated from the results of its weighings and the data from the 3 panels of each species and treatment were averaged together. The results for the spruce panels are given in Figure 8. The ash panels gave substantially the same results as the spruce. The curves in Figure 8 show how large the fluctuations were in the uncoated panels and how greatly they were reduced by the coatings. The superiority of the aluminum-leaf coating over the varnish coating was very marked. The lowest moisture content reached by the aluminum-coated spruce panels was 8.4 per cent, at Flagstaff, Ariz.; the highest was 13.4 per cent, at Valparaiso, Fla., which gives a maximum variation of 5 per cent. Similarly the varnished spruce panels showed a maximum variation of 10.9 per cent between the low value of 6.2 per cent, at Flagstaff, and the high value of 17.1 per cent, at Valparaiso. The highest value for uncoated spruce panels was 22.9 per cent, at Priest River, Idaho; the lowest 5.3 per cent, at Flagstaff, Ariz., a maximum variation of 17.6 per cent.

SUMMARY

On account of the great importance of preventing dimension changes in wood with changing atmospheric conditions, attempts have been made for many years to devise coatings or treatments that will "moisture proof" wood. No method or material has yet been discovered which will completely prevent moisture changes in wood, but it has been found practical, by the use of suitable coatings, to reduce the rate of moisture absorption very materially and thus reduce, if not entirely eliminate, some of the troubles due to moisture changes.

Hundreds of experiments have been made at the Forest Products Laboratory in the last 15 years in the search for the most effective coatings, and over 2,000 test panels have been exposed in long-time weather tests. The work is still in progress and will undoubtedly

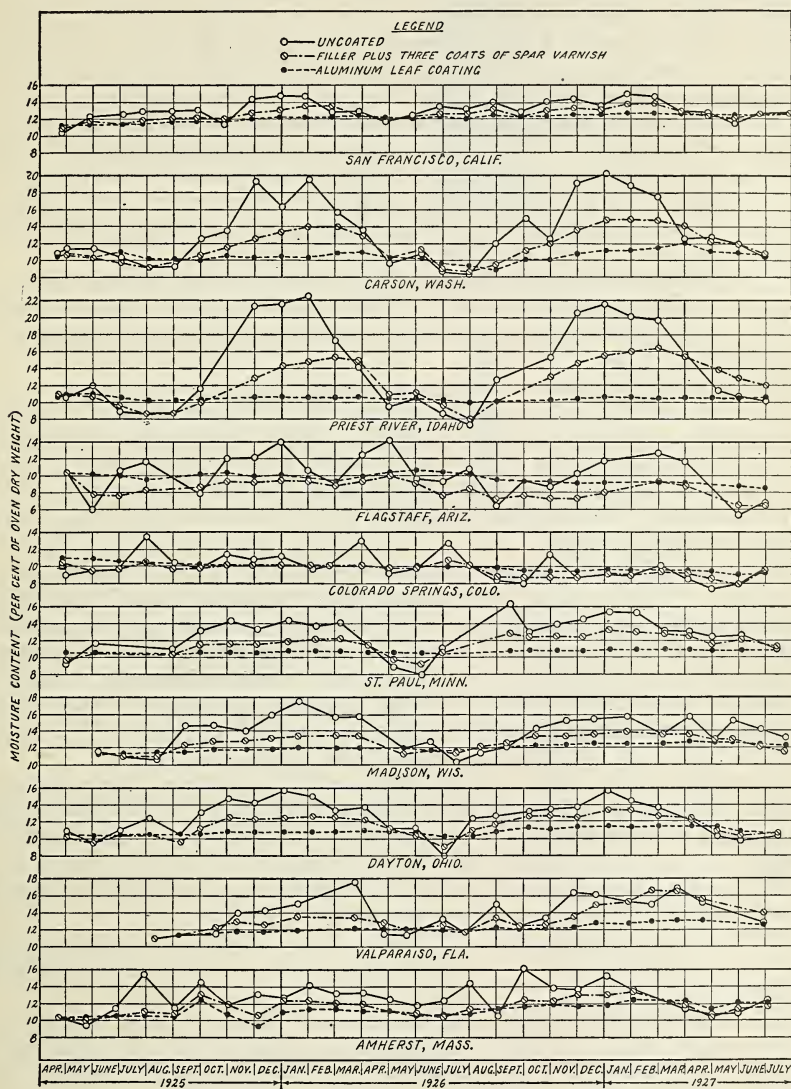


FIGURE 8.—Seasonal fluctuations in moisture content of spruce panels at various locations in the United States

continue for some years to come. No perfect moisture-proof coating has yet been found, but the following useful conclusions have been reached thus far in the course of the work.

The most effective moisture-resistant coatings found for wood were those containing aluminum leaf between coats of other materials,

such as paint, varnish, or the like. For exterior exposure, linseed-oil paint was found very effective for use with the aluminum leaf because it stood up well under weathering. For interior use with the leaf either varnishes, enamels, or paints were found suitable.

Coatings of varnish, enamel, or paint containing aluminum powder were next in effectiveness to aluminum-leaf coatings. Such coatings, when properly applied and maintained, reduced the rate of moisture change in wood so that when exposed to practically saturated air for two weeks only about 5 to 10 per cent as much moisture entered the coated wood as entered similar wood uncoated. Good paints of the linseed-oil, bituminous, or asphaltic type, containing aluminum powder maintained their effectiveness throughout long periods of exposure to the weather. Some of the best coatings of the linseed oil-aluminum powder type maintained better than 90 per cent effectiveness after more than two year's exposure to the weather.

The moisture-excluding effectiveness of red lead and orange mineral pigment paints increased notably with increasing percentage of pigment, and a still further increase was effected by the addition of aluminum powder.

Of the many asphaltic, bituminous, and similar paints tested, a few were very effective, but since all were proprietary paints of secret composition, no generalizations can be made. Furthermore, since the formulæ and character of the paints tested are subject to variation at any time, and are very difficult to check by chemical analysis, only such confidence can be placed in them as can be attached to the manufacturers' reputation.

Spar varnishes were found moderately effective in retarding moisture changes. Wood properly dried and then varnished on all sides fluctuated much less in moisture content under changing atmospheric conditions than unvarnished wood. In using spar varnishes, increasing effectiveness was observed as the number of coats increased. Dipped coatings were more effective than brushed coatings. Oven-dried coatings were similar in effectiveness to air-dried coatings. The addition of pigments to varnishes made them more effective.

Varnishes made with artificial resins of the bakelite type appeared to be superior in moisture-excluding effectiveness to ordinary spar varnishes, but generalizations concerning the artificial resin varnishes tested are not dependable since their composition was not known.

High effectiveness was found in a proprietary paint said to contain a lead suboxide as its principal pigment.

Thorough impregnation with sugar, while ineffective in preventing moisture changes, greatly reduced dimension changes with changing moisture content.

The moisture-excluding effectiveness of impregnation treatments as compared with coatings was not adequately studied, but the indications are that deep impregnation is not so necessary as a continuous film over the surface.

Coatings or treatments with linseed oil, floor wax, and the like, were low in effectiveness.

